IMAGING THE RELATIVISTIC COMPONENT OF THE LARGE SCALE STRUCTURE

Maxim Markevitch (NASA GSFC), maxim.markevitch@nasa.gov

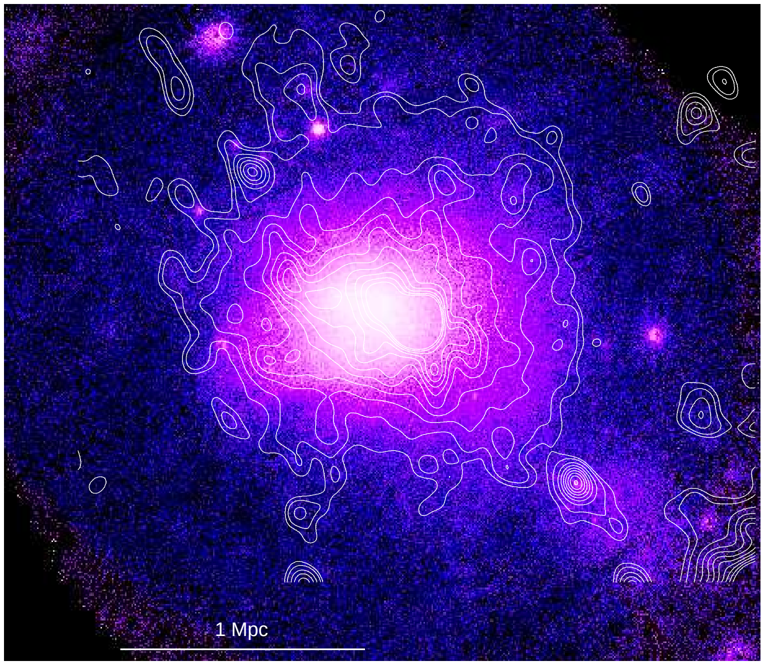

Fig. 1— The Coma cluster. Color shows soft X-rays (0.5–2 keV, *ROSAT* PSPC) from thermal gas. Contours show synchrotron radio emission (*Westerbork*, 350 MHz, Brown & Rudnick 2010) from ultrarelativistic electrons. Relativistic electrons in clusters have never been observed directly — only in combination with the highly uncertain magnetic field.

Profound science results have been obtained in the past decades by X-ray instruments sensitive in the soft, $E = 0.3-10$ keV, energy band. *Einstein*, *ROSAT*, *ASCA*, *Chandra*, *XMM* and *Suzaku* were able to discover and study the faint, diffuse X-ray signal from a variety of astrophysical sources dominated by thermal emission, such as galaxies and galaxy clusters. Other highly productive X-ray observatories, such as *HEAO*-1, *Ginga*, *Granat*, *RXTE*, *SWIFT*, had large effective areas at higher energies ($E > 10$ keV), but lacked true imaging capabilities, resorting to collimators or coded masks. For this reason, they were mostly limited to bright compact sources, such as Galactic binaries and brightest AGN. At present, there remains a large and totally unexplored discovery space of faint, diffuse nonthermal astrophysical objects emitting at high X-ray energies.

Just one class of such sources waiting to be discovered is cosmic rays in galaxy clusters and in the filaments of the Large Scale Structure (LSS). Most of the visible matter in the Universe is in the form of diffuse intergalactic gas that fills those giant structures. It is heated to $T = 10^{6-8}$ K by shocks that accompany the growth of LSS. Those same shocks should accelerate electrons to ultrarelativistic ($\gamma = 10^{3-4}$) energies. The presence of such electrons in galaxy clusters is revealed by synchrotron radio halos found in some merging systems and by peripheral radio "relics" believed to trace shocks. These cosmic rays (CR) and magnetic fields can alter the cluster plasma physics in very significant ways. Apart from purely astrophysical interest, full understanding of the cluster physics is necessary to realize the promise of galaxy clusters as a tool for precision cosmology.

The synchrotron brightness is proportional to B^2 (where B is the magnetic field) and cannot separate the CR electron density from the unknown magnetic field. It is also strongly weighted toward the cluster central regions with stronger fields, missing the sites where CR production is most efficient — at stronger shocks in the cluster periphery and LSS filaments. However, relativistic electrons also emit via inverse Compton (IC) upscattering of the CMB photons, making them potentially observable by hard X-ray imaging instruments.

Detecting IC emission from clusters is both a scientific and a technological challenge. The hard X-ray telescopes onboard *NuSTAR* and the forthcoming *Astro-H* are going to graze the surface of this discovery space, perhaps detecting IC from 1-2 brightest relics. *Fermi* is likely to obtain only the upper limits on the density of the cosmic ray protons in clusters. For realistic intracluster magnetic fields, to detect and study IC emission from the bulk of the cluster CR electron population that generates a typical giant radio halo, one needs an effective area ~ 30 times that of NuStar, or about 1 m^2 at $E = 30$ keV. Such a hard X-ray imaging telescope, working in tandem with future giant radio arrays such as SKA, could open an entirely new field of astrophysics — cosmic rays and magnetic fields in the LSS — and would undoubtedly bring discoveries in other fields.